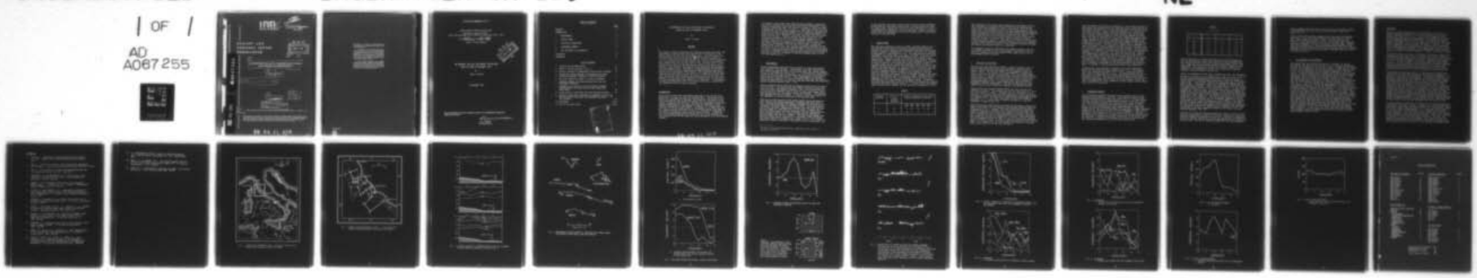
AD-A067 255 SACLANT ASW RESEARCH CENTRE LA SPEZIA (ITALY) F/G 8/3
LOW-FREQUENCY SEA-LEVEL AND CURRENT FLUCTUATIONS ALONG THE COAS--ETC(U)
NOV 78 A J ELLIOTT

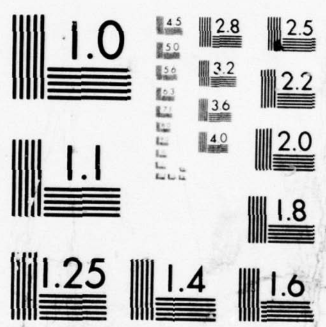
UNCLASSIFIED SACLANTCEN-SM-119 NL

1 OF 1

AD
A067 255



END
DATE
FILMED
6 --79
DDC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

LEVEL II

SACLANTCEN ~~Memorandum~~
SM – 119

SACLANT ASW RESEARCH CENTRE MEMORANDUM

DDC
RECEIVED
APR 13 1979
C

LOW-FREQUENCY SEA-LEVEL AND CURRENT FLUCTUATIONS ALONG THE COAST OF NORTHWEST ITALY

by

ALAN J. ELLIOTT

Memorandum rept.,

15 NOV[redacted]R [redacted]78

24p.

NORTH ATLANTIC TREATY ORGANIZATION

LA SPEZIA, ITALY

Published by

STI

SACLANTCEN MEMORANDUM SM-119

NORTH ATLANTIC TREATY ORGANIZATION

SACLANT ASW Research Centre
Viale San Bartolomeo 400, I-19026 San Bartolomeo (SP), Italy.

tel: national 0187 503540
international + 39 187 503540

telex: 271148 SACENT I

LOW-FREQUENCY SEA-LEVEL AND CURRENT FLUCTUATIONS ALONG THE COAST OF NORTHWEST ITALY

by

Alan J. Elliott

15 November 1978

This memorandum has been prepared within the SACLANTCEN Underwater Research Division.

G.C. VETTORI
Division Chief

TABLE OF CONTENTS

List of Figures

LOW-FREQUENCY SEA-LEVEL AND CURRENT FLUCTUATIONS ALONG THE COAST OF NORTHWEST ITALY

by

Alan J. Elliott

ABSTRACT

An analysis is made of two-month long records of current, sea level, and wind stress, collected during April and May 1977 at locations in the shallow waters off the coast of northwest Italy. The mean current was directed along the coast towards the northwest and had a strength of 5.0 to 6.0 cm/s; this flow continued past the island of Elba, progressing from the Tyrrhenian Sea into the Ligurian Sea. Sea-level fluctuations were coherent along the Ligurian coast of Italy and were due to a wind-induced set-up caused by the semi-enclosed nature of the basin; only a fraction of the sea level disturbances in the Tyrrhenian Sea propagated into the Ligurian basin. There was no coherence between the near-shore current and the sea level, suggesting that shelf waves may play only a minor role in the dynamics of the region. The alongshore currents were coherent with each other and with the wind at a time scale of about five days. This agrees with the period of cyclone activity in the area, and suggests that the shelf waters responded coherently when the wind field was well organized during the formation of a depression. In consequence, an adequate hydrodynamic model of the region would need to couple both the atmospheric and the coastal response.

INTRODUCTION

During April and May 1977 measurements were made in the shallow shelf waters that lie along the coast of northwest Italy. The purpose of the study was to determine the character and strength of the mean currents and to estimate the time scales associated with the fluctuations in the coastal circulation and sea level. The work was undertaken to obtain an improved understanding of the mechanisms that can contribute to the acoustic variability of shelf waters. Ultimately, it is hoped that this will lead to a better understanding of the variability of sound speed in the coastal zone and that this, in turn, will allow better prediction of the acoustic propagation through shallow coastal waters. In addition, since the present observations are among the first to be reported for this portion of the Italian coastline, the investigation is of environmental interest.

It is only in recent years that there have been attempts to determine the dynamic character of the sea level and current fluctuations in this region, previous work being restricted to the study of tidal and higher frequency oscillations (e.g. *[1]* and *[2]*). There has not been any prior investigation into the coastal dynamics of this region at the storm-time scale (2 to 20 days), and the present *in-situ* current measurements are among the first to be reported in the open literature* for this portion of the Italian coast. Previous studies into the circulation of the Ligurian and Tyrrhenian Seas relied upon indirect methods such as isentropic analysis (e.g. *[3]*) or the geostrophic method (e.g. *[4]*). The mean circulation is thought to be a cyclonic gyre of surface water that enters the southern Tyrrhenian Sea from the west through the channel south of Sardinia. Part of this flow passes eastwards through the Strait of Sicily, while the remainder moves along the northern coast of Sicily, flows up the western coast of Italy, and then turns southwards near Elba to complete the gyre by moving down the east coast of Sardinia. A portion of the flow is thought to continue northwards past Elba and into the Ligurian Sea *[5]*.

1 MEASUREMENTS

Current measurements were made at two locations in water approximately 100 m deep and 15 km offshore. The moorings, which were 100 km apart, were located on opposite sides of the shallow water that extends between the Italian mainland and Corsica (Fig. 1). A third mooring, placed 100 km further to the south near Civitavecchia, was lost during the experiment and no data are available from it. Three oceanographic cruises were made at monthly intervals to survey the coastal waters near the mooring positions; meteorological and sea-level data were obtained from established coastal recording stations (Figs. 1 & 2).

Each sub-surface mooring supported two Aanderaa current meters at depths of 20 m and 80 m. The data series were lowpass filtered to remove the tidal and other high-frequency components; the filter spanned 100 hours of data and had a response close to unity for time scales longer than 2 days and near-zero for time scales shorter than 25 hours. The data were then resampled at 6-hour intervals. A similar filtering was applied to the components of the wind stress and to the sea-level data.

There was a uniform warming of the coastal waters during the months of April and May, the surface temperature increasing from about 14°C to 18°C. Near-bottom temperatures remained unchanged and the warming was confined to the upper layers of the water column. Since there were no significant horizontal temperature gradients along the coast and there was no evidence of a warm water mass to the south, it appears that advective effects were relatively unimportant and that the warming was due to seasonal heating *[6]*. Figure 3 shows vertical temperature sections taken along the 100 m isobath. The water column changed from being well-mixed during late March to a stratified column during May. The stratification was strongest near a depth of 15 m. The increase in temperature caused a reduction in the density of the surface water, and

---

* *The text of this memorandum has been submitted to the Journal of Geophysical Research.*

at both locations the water column changed from being almost isothermal during March to a two-layered system, with a surface mixed-layer about 10 m deep in May. During the first half of the experiment all of the current meters lay beneath the surface mixed-layer. However, during the second month the instruments at 20 m were located either in the thermocline or in the mixed-layer.

2 COASTAL WINDS

Wind data were obtained for the five coastal locations shown in Fig. 1. The data were in the form of ten-minute averages of wind speed and direction at hourly intervals; the values were converted to wind stress through a quadratic relationship *[7]* so that a wind stress of 1 dyn/cm^2 corresponded to a wind speed of 8.0 m/s. The east-west and north-south components of the stress were then lowpass filtered. There was significant spatial variability in both the strength and direction of the lowpass winds. Whereas the mean stress at the three southern stations (Civitavecchia, Olbia, and Ponza) was directed eastwards with a strength of about 0.5 dyn/cm^2, at Pisa the mean stress was about an order of magnitude weaker and was towards the north-east, while at Genova it was towards the north-west (Fig. 4). The anticlockwise rotation of the mean wind may have been caused by cyclogenesis *[8]*, or it may have been due to local orographic effects. To resolve the structure of the wind, empirical orthogonal function analysis *[9]* was applied to the five series of east-west wind stress. Of the five modes isolated (since there were five input series) the first mode was highly correlated with the components of stress at Pisa, Civitavecchia, Olbia, and Ponza, but explained only 1% of the variance in the Genova record. In contrast, the second mode accounted for 95% of the Genova variance but was uncorrelated with the other locations (Table 1). A similar result was obtained when the analysis was repeated for the north-south components of stress.

TABLE 1

Empirical function	Percent of total variance explained	Percent of variance in each input series explained by function				
		GEN	PSA	OLB	CIV	PON
1	58	1	63	64	77	84
2	21	95	0	8	1	1

This partition of the wind records suggested that the Genova wind had been influenced by orographic effects, therefore the remaining four vector series were averaged to produce a time series of the 'large-scale' wind. The geostrophic wind, calculated from atmospheric pressure measured at Genova, Olbia, and Ponza, was not coherent with the observed winds, probably due to the pronounced curvature of the isobars. The large-scale wind stress was directed towards the east and the fluctuations were greatest in the east-west direction (having a standard deviation of about 1 dyn/cm^2). There were also significant fluctuations in the northwest-southwest (alongshore) direction, and in the northwest-southwest (on/offshore) direction; in the alongshore direction the mean wind stress was directed towards the south-east.

The atmospheric pressure distribution was coherent spatially over all five weather stations for time scales between 3 and 20 days, and the pressure systems were moving southwards with a phase lag of 5 to 10 hours between Genova and Ponza.

3 SEA-LEVEL FLUCTUATIONS

Sea-level data were obtained for Genova, Livorno, and Napoli (Fig. 1) and the hourly data were filtered and decimated to obtain 6-hourly values. Spectra and coherence between the non-adjusted records are shown in Fig. 5. The spectral levels were comparable at Genova and Livorno and these two records were coherent at all time scales longer than 2.5 days. In contrast, the Napoli data contained considerably more variance and were coherent with the Ligurian sea level only for time scales longer than 5 days. All three sea-level records suggested a southward propagation with a speed comparable to that found for the atmospheric pressure disturbances. Thus the non-adjusted sea levels appear mainly to have reflected the passage of the pressure systems.

Figure 6 shows the coherence between Genova sea level and the local atmospheric pressure. The coherence was high for time scales of 3 to 20 days, particularly at 5 days. Coherence was also significant at 2 to 2.5 days. At the 5-day time scale the response was close to hydrostatic, the transfer function between the two signals having a magnitude of 0.95 and a phase of 175°. For other time scales the sea level tended to overshoot, i.e. a 1 mbar change in pressure resulted in a sea-level adjustment of greater than 1 cm.

After the sea-level data had been corrected for atmospheric pressure the shape of the spectra and the coherence relationships remained similar to those shown in Fig. 5. However, the phase differences now suggested a northward-travelling disturbance with a period of around 10 days. The speed of propagation of this wave was estimated to be around 100 km/h; this is probably too fast for the disturbance to have been a shelf wave, even though its direction of propagation is correct. Using the formula for the fundamental barotropic mode *[10]*, we can calculate the expected speed to be about 12 km/h: an order of magnitude slower than the observed speed. This suggests that the disturbances were generated in the deep water and were arriving at the coast obliquely.

Since the Genova wind had been considered as a local feature and had not been used in the calculation of the large-scale wind, it was possible to investigate the effects of both local and non-local wind forcing on the sea level at Genova. Figure 7 shows the coherence, as a function of wind direction, between Genova sea level and both local and non-local wind. The sea level rose when the local wind blew towards the north-west (135°) with a time scale of 3 to 5 days, lagging the wind by about 1 day. Neither the Livorno nor the Napoli sea level responded to wind blowing parallel to the coast, therefore this response at Genova was probably due to a set-up caused by the blocking effect of the coastline to the west of Genova. The local wind at Genova was not important at other time scales. Higher coherence was found for the large-scale wind, with both Genova and Livorno showing a similar response. At both ports the sea level responded to the east-west wind but not to the north-south component. At time scales of 2 to 3 days the sea level was raised by the eastward wind, suggesting a set-up of the Ligurian Sea. However, for periods longer than 10 days the wind and sea level were out of phase, and therefore either rotation or a larger spatial scale response was important. The response of the sea level at Napoli to the large-scale wind was not as coherent as that found for Genova and Livorno; this is probably a consequence of the open character of the coast near Napoli in contrast to the semi-enclosed nature of the Ligurian Sea.

The Genova sea level appeared to respond to the forcing mechanisms within distinct frequency bands (compare Figs. 6 & 7). The pressure effect was strongest at periods of 3 to 10 days, especially around 5 days, and in a narrow band at 2.5 days. The winds provided forcing at time scales for which there was low coherence between sea-level and atmospheric pressure: the large-scale wind was coherent with Genova sea level at periods longer than 10 days, at 2.5 days, and at 2 days; the local wind appeared to be less important and was coherent with sea level only at the 4 to 5 day scale.

4 ALONGSHORE CURRENTS

The current-meter data were filtered and then resolved into the local alongshore and on/offshore directions. The resulting vectors, along with the large-scale wind stress, are shown in Fig. 8. At both mooring locations the mean flow was approximately parallel to the local coastline and was directed towards the north-west with a speed of about 4 cm/s. The flow reversed and went towards the south-east only during periods of strong southeastward winds, suggesting that an underlying density-driven flow was directed towards the north-west. Linear regression showed that for zero wind the mean flow was independent of depth and was directed to the north-west at 5.0 to 6.0 cm/s (Table 2). The good agreement in the estimates of the mean flow at the two locations confirms the existence of a mean current along this portion of the Italian coast, and shows that a component of the mean surface flow in the Tyrrhenian Sea continues northwards past Elba into the Ligurian basin.

TABLE 2

$$y = a_x + b$$

y	a	b	r^2
N_{20}	1.9	4.9	0.22
N_{80}	14.3	5.3	0.17
S_{20}	2.4	4.9	0.13
S_{80}	12.5	6.5	0.27

Table 2 shows that on average about 20% of the current fluctuations could be explained by a linear relationship with the alongshore wind. For a given wind stress the current response was greater at 80 m than 20 m, suggesting that the shallow meters were being influenced by the thermocline. The alongshore currents had a maximum response to the component of the wind parallel to the coast; there was no coherent response in the on/offshore direction *[6]*.

Spectra for alongshore current (N_{80}), adjusted sea level, and atmospheric pressure at Livorno, and the alongshore wind stress are shown in Fig. 9. All the spectra showed maxima at time scales of 20 days or longer, a gradual decrease in energy between 20 days and 3 days, and little energy below 3 days. In particular, there was no pronounced spectral peak at around 5 days. (The spectra shown have 14 degrees of freedom and have been smoothed considerably. Higher resolution spectra with fewer degrees of freedom showed essentially the same spectral levels, i.e. we have not averaged out a peak at 5 days — the significance of this statement will become clear in the following discussion.) At the northern mooring the current fluctuations were coherent between 20 m and 80 m for time scales longer than 3 days. However, at the southern mooring the two levels were incoherent at all frequencies. Only the currents measured by the two meters at 80 m were coherent over the alongshore separation of 100 km; the currents at 20 m were incoherent over this distance. The coherence between the deeper records was highest around a time scale of 5 days. For part of the time the upper meters were influenced by the mixed-layer and reflected the baroclinic component of the response; this will have contributed to the poor alongshore coherence at 20 m and to the poor vertical coherence. (Fig. 10)

Figure 10 also shows the coherence between the currents at 80 m and the sea level and atmospheric pressure at Livorno. There was no significant coherence between the alongshore current and the sea-level fluctuations, while the coherence between the current and pressure was only significant around 5 days. The lack of coherence between sea level and alongshore current suggests that shelf waves were not part of the coastal response since they would link sea level and current through a cross shelf balance *[11, 12]*.

Figure 10 shows the coherence between the currents and the alongshore wind stress. There was a broad coherence for time scales of 3 to 10 days, with the peak occurring at 5 days. Thus both the sea level (Figs. 6 & 7) and the currents (Fig. 10) in this region show a coherent response to atmospheric forcing for periods of around 5 days. However, the forcing functions (i.e. wind and pressure) have predominantly red spectra, as do the current and sea level records (Fig. 9); it is therefore necessary to explain why the coastal waters responded coherently only at the 5-day time scale.

5 THE INFLUENCE OF CYCLOGENESIS

The Ligurian Sea, and in particular the Gulf of Genova, is an area favoured for the generation of cyclones *[13]*; on average 52 depressions per year can be expected to form in this region. A suggestion of cyclonic activity has already been given by the progressive vector diagrams shown in Fig. 4, which emphasise the low-frequency components of the wind stress. To obtain a quantitative estimate of the wind's cyclonic energy the curl of the wind-stress vector was computed using the wind records from Genova, Olbia, and Ponza; its spectrum is shown in Fig. 11. The wind-stress curl had a broad peak in energy centred on a period of 5 days and extending over time scales of from 3 to 10 days. To demonstrate that the curl of the wind stress was a reliable indicator of cyclonic flow, Fig. 11 shows the coherence and phase between the wind-stress curl and atmospheric pressure. During the development of a cyclone the two parameters should be coherent and out of phase, i.e. the cyclonic rotation of the wind should increase as the pressure falls. This relationship held for time scales of from 3 to 10 days, especially at 5 days. Thus, during the two-month study period the wind field had a coherent, spatial, cyclonic structure with an associated time scale of 5 days; this agrees with the average occurrence interval of about one cyclone per week. The data suggest that during cyclonic activity the organized structure of the wind field is more efficient at driving the coastal currents and that this explains the high coherence at the 5-day time scale. For example, at other frequencies, the wind near Genova may have been driving water southwards while the wind near Napoli was driving the coastal water northwards. It was only at the 5-day time scale that the wind field assumed a spatially coherent structure and the coastal response became coherent along the shelf.

DISCUSSION

Much of our present knowledge of coastal dynamics is the result of studies conducted along relatively straight coastlines, e.g. the west coast of the United States *[11, 12, 14]*, where the response can be modelled analytically using simple geometry, and alongshore variations in the bottom topography can be neglected. In contrast, the coastal waters of northwest Italy lie on the edge of two deep basins where water depths exceed 2500 m and the coastal topography is irregular. In this region, therefore, the bottom geometry is likely to play a significant role in determining the response of the coastal waters to wind forcing, and it will probably be necessary to use hydrodynamics models that can resolve the effects of bottom topography to predict the coastal response.

The present analysis has used a 'large-scale' wind that was obtained by computing the vector mean of several coastal wind records. However, in view of the significant cyclonic structure of the wind it may be necessary to specify the wind everywhere (as is done in modelling storm surges, e.g. *[15]*) in order to obtain a satisfactory prediction of the coastal response. Since the predicted coastal currents will be highly dependent on the wind distribution used in the modelling, this suggests that effort should be put into measuring the wind directly at sea and into determining the reliability of the wind measured at coastal stations.

The data have not produced evidence for the presence of coastal waves, although the sea-level stations may have been too close together to permit this to be done with confidence. The observed disturbances, with periods of around 10 days, did propagate in the correct direction and had greater amplitude at Napoli than at the northern stations. However, the speed with which they travelled was nearly an order of magnitude faster than that calculated for the first barotropic mode. In the Ligurian Sea the main response in sea level was due to the on/offshore component of the wind and this was attributed to a set-up caused by the semi-enclosed nature of the basin, causing the sea levels at Genova and Livorno to be highly coherent. The coherence in sea level was lower between the two basins, suggesting that only a fraction of the sea-level disturbances in the Tyrrhenian Sea travelled into the Ligurian Basin. However, comparable estimates of the magnitude of the alongshore density-driven flow were obtained at the two mooring locations, confirming that the mean surface flow continues northwards past the island of Elba.

The high coherence found at the 5-day time scale has been attributed to cyclogenesis in the Gulf of Genova. However, it is also possible that a time scale of this order could be associated with a closed-basin response of the entire Western Mediterranean, i.e. a rotational normal mode of the western basin. The measurements did not support this, however, since a response of this type would involve coastal waves and a coupling between nearshore currents and surface elevation. There was no evidence in the data of a cross-shelf geostrophic balance of this type. The apparent role played by cyclones suggests that future work should be directed towards resolving the structure of the weather systems and of their coupling with the circulation in the Ligurian and Tyrrhenian Seas.

REFERENCES

1. LUSETTI, C. Osservazioni mareografiche del porto di Genova, F.C. 1079. Genova, Italy, Istituto Idrografico della Marina, 1977.

2. PAPA, L. The free oscillations of the Ligurian Sea computed by the H-N method. *Deutsche Hydrographische Zeitschrift* 30, 1977: 81-90.

3. WUST, G. On the vertical circulation of the Mediterranean Sea. *Jnl Geophysical Research* 66, 1961: 3261-3271.

4. KRIVOSHEYA, V.G. and OVCHINNIKOV, I.M. Peculiarities in the geostrophic circulation of the waters of the Tyrrhenian Sea. *Oceanology* 13, 1973: 822-827.

5. SANKEY, T. The formation of deep water in the northwestern Mediterranean. *In:* WARREN, B.A. *ed.* Progress in Oceanography, Oxford, Pergamon, 1973: pp 159-179.

6. ELLIOTT, A.J. and STROBEL, F. de. Oceanographic conditions in the coastal waters of northwestern Italy during the spring of 1977, SACLANTCEN SM-116. La Spezia, Italy, SACLANT ASW Research Centre, 1978.

7. HALPERN, D. Measurements of near-surface wind stress over an upwelling region near the Oregon coast. *Jnl Physical Oceanography* 6, 1976: 108-112.

8. CANTU, V. The climate of Italy. *In:* WALLEN, C.C. *ed.* Climates of Central and Southern Europe, World Survey of Climatology Volume 6. Amsterdam, Elsevier, 1977: pp 127-173.

9. WALLACE, J.M. and DICKINSON, R.E. Empirical orthogonal representation of time series in the frequency domain, Part I: Theoretical considerations. *Jnl Applied Meteorology* 11, 1972: 887-892.

10. ROBINSON, A.R. Continental shelf waves and the response of sea level to weather systems. *Jnl Geophysical Research* 66, 1964: 367-368.

11. KUNDU, P.K., ALLEN, J.S., and SMITH, R.L. Modal decomposition of the velocity field near the Oregon coast. *Jnl Physical Oceanography* 5, 1975: 683-704.

12. HUYER, H., HICKEY, B.M., SMITH, J.D., SMITH, R.L., and PILLSBURY, R.D. Alongshore coherence at low frequencies in currents observed over the continental shelf off Oregon and Washington. *Jnl Geophysical Research* 80, 1975: 3495-3505.

13. U.K. METEOROLOGICAL OFFICE. Weather in the Mediterranean, Vol. I (2nd Ed) General Meteorology, M.O. 391. London, HMSO, 1962.

14. WANG, D.-P. and MOOERS, C.N.K. Long coastal-trapped waves off the west coast of the United States, Summer 1973. *Jnl Physical Oceanography* 7, 1977: 856-864.

15. HEAPS, N.S. A two-dimensional numerical sea model. *Philosophical Transactions — Royal Society* A 265, 1969: 93-137.

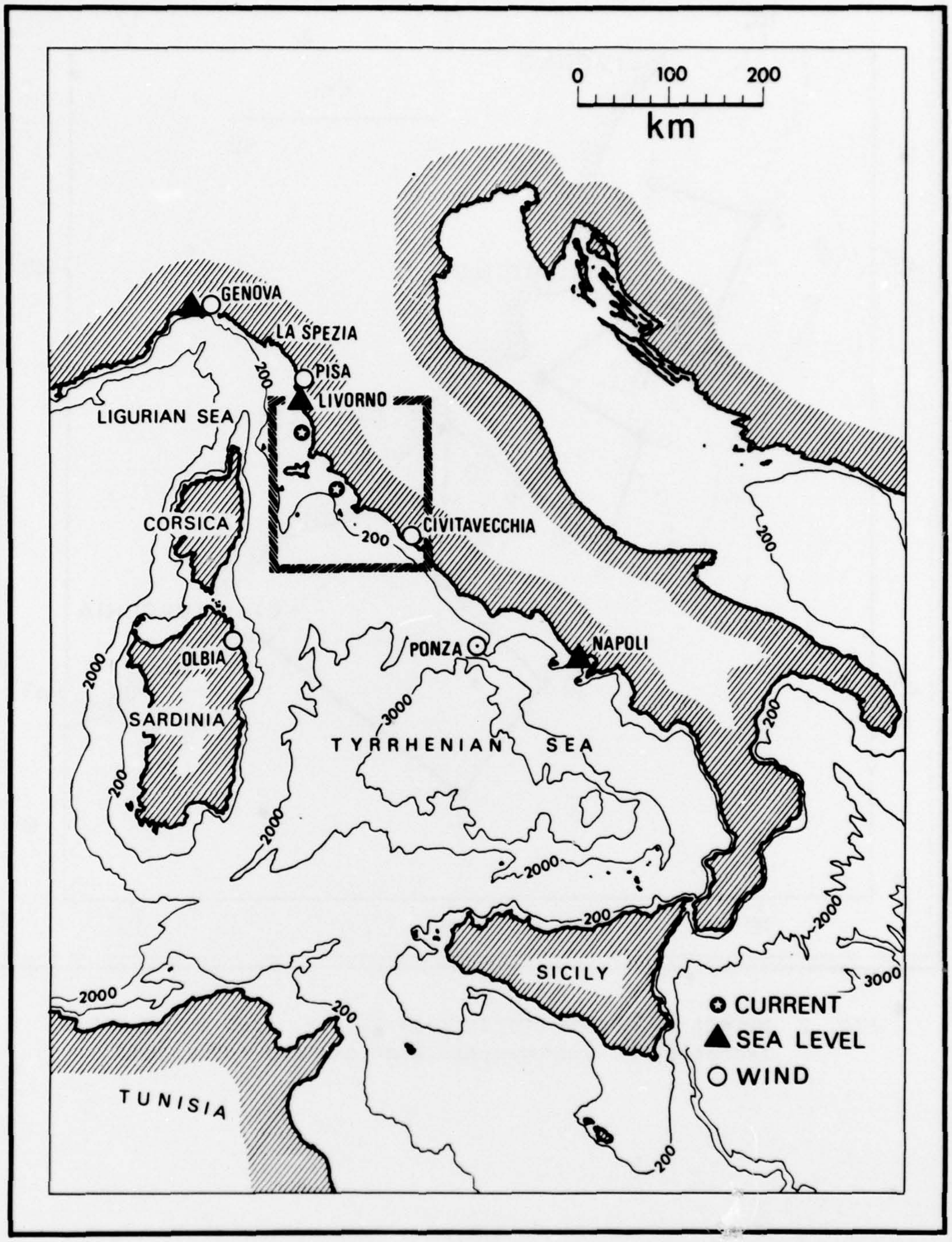


FIG. 1 LIGURIAN AND TYRRHENIAN SEAS. Location of moorings and weather and sea-level stations are shown.

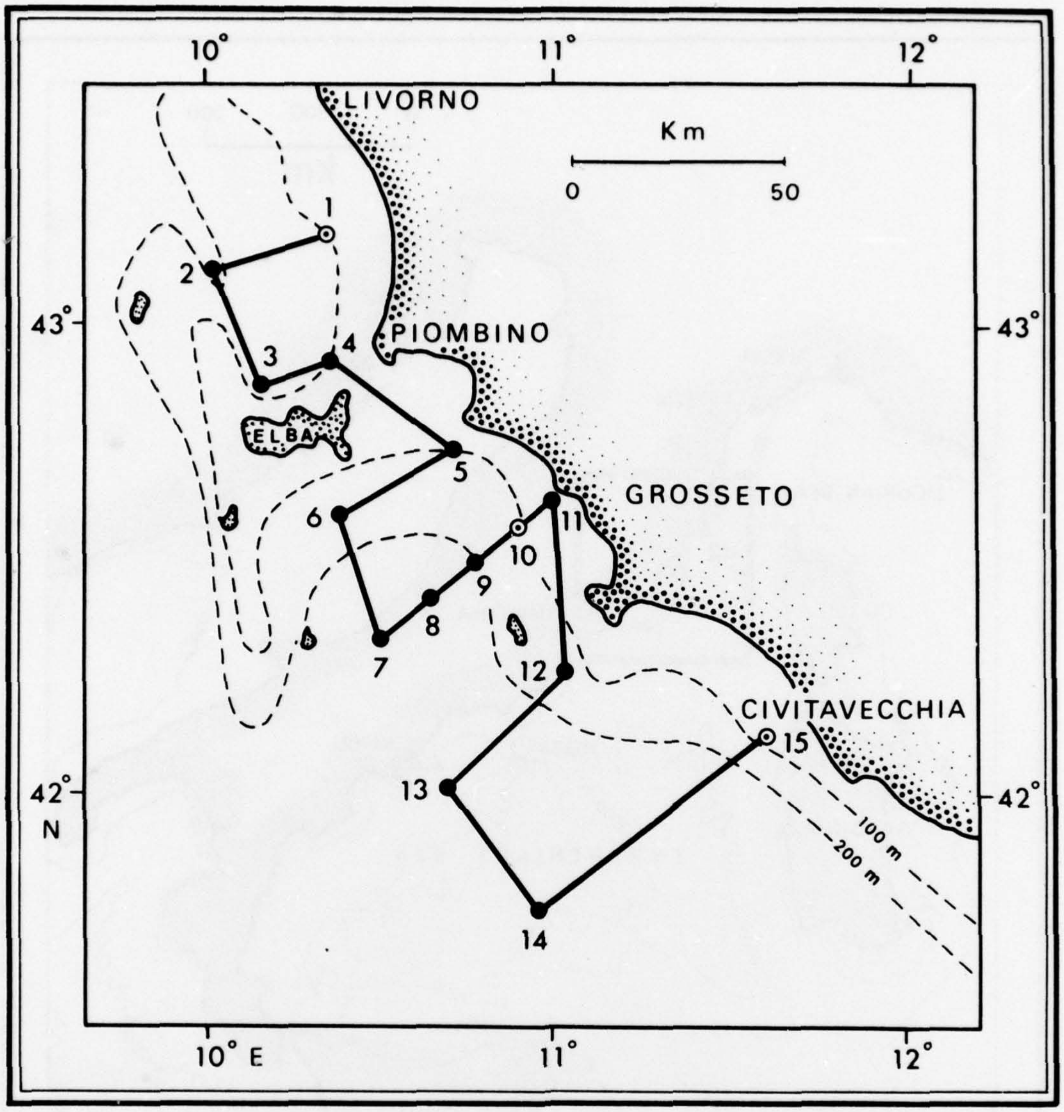


FIG. 2 DETAIL OF REGION OUTLINED IN FIG. 1. 100 m and 200 m isobaths and hydrographic stations are indicated.

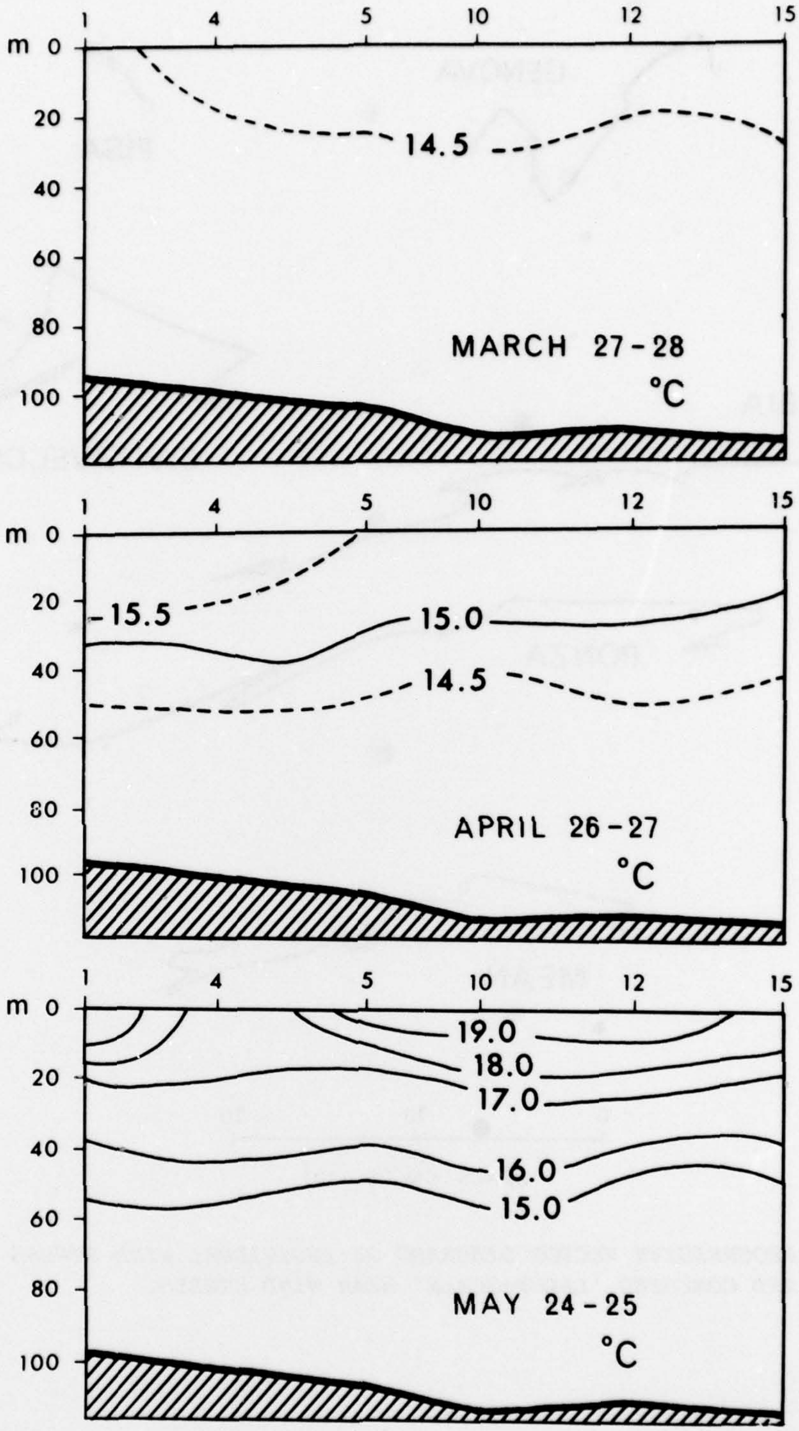


FIG. 3 VERTICAL SECTIONS OF TEMPERATURE ALONG THE 100 m ISOBATH. Station numbers correspond to those in Fig. 2.

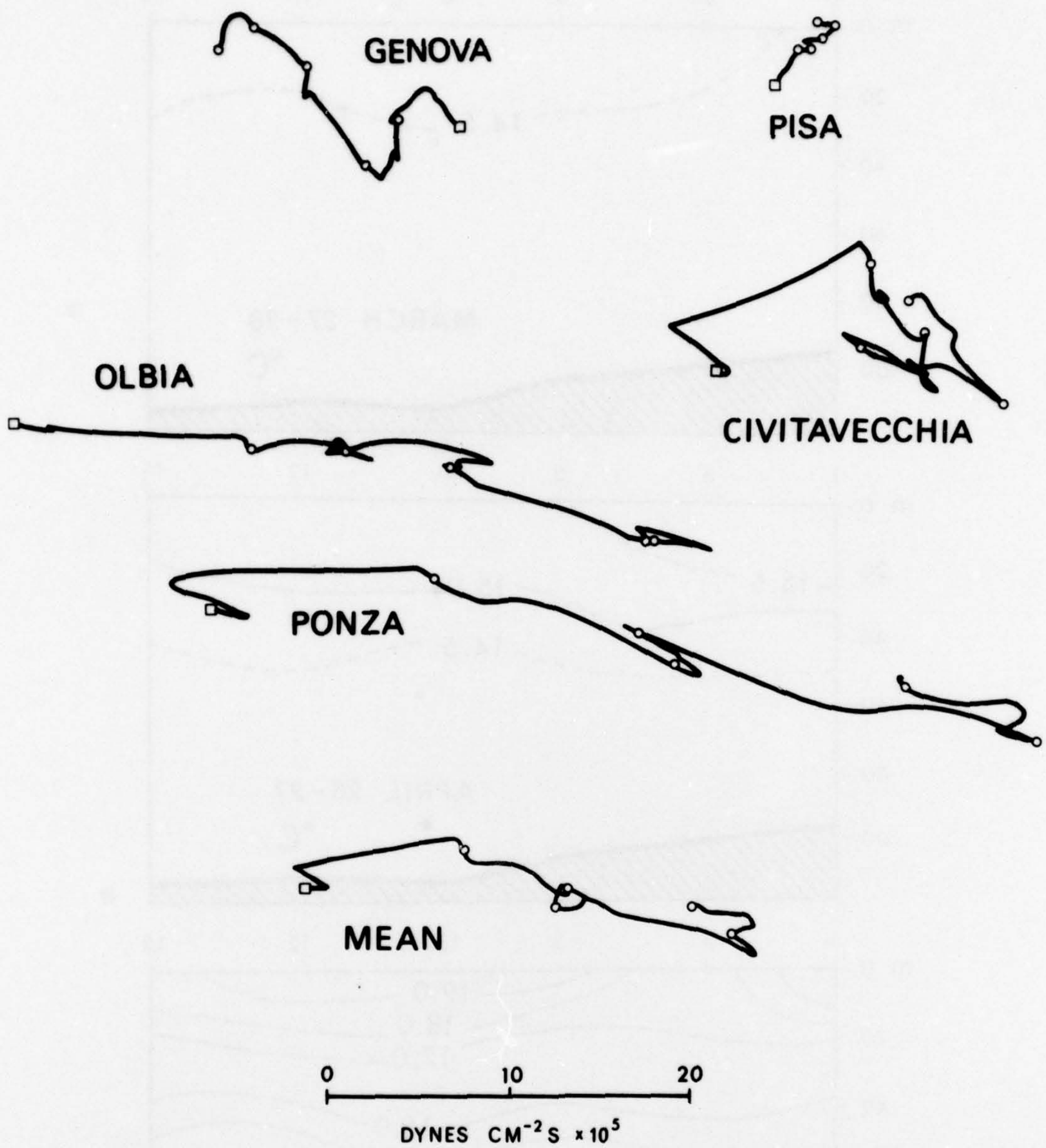
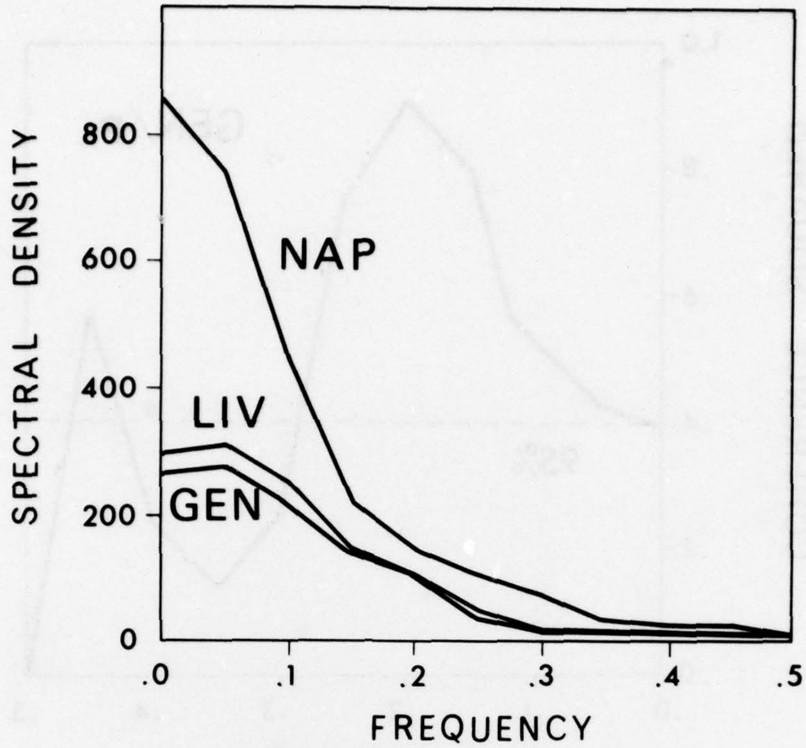
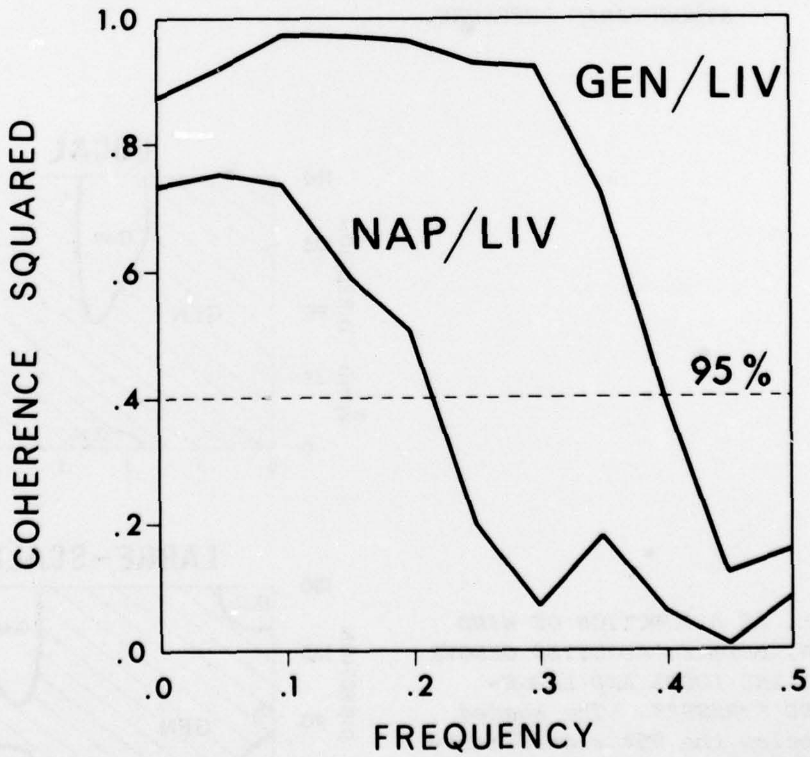


FIG. 4 PROGRESSIVE VECTOR DIAGRAMS OF INDIVIDUAL WIND STRESS SERIES AND COMPUTED 'LARGE-SCALE' MEAN WIND STRESS.



a. Non-adjusted records.



b. Coherence between Napoli and Livorno, and between Genova and Livorno (spectral density in cm^2/(cycles/day).

FIG. 5 SEA LEVEL SPECTRA FOR NAPOLI, LIVORNO, AND GENOVA.

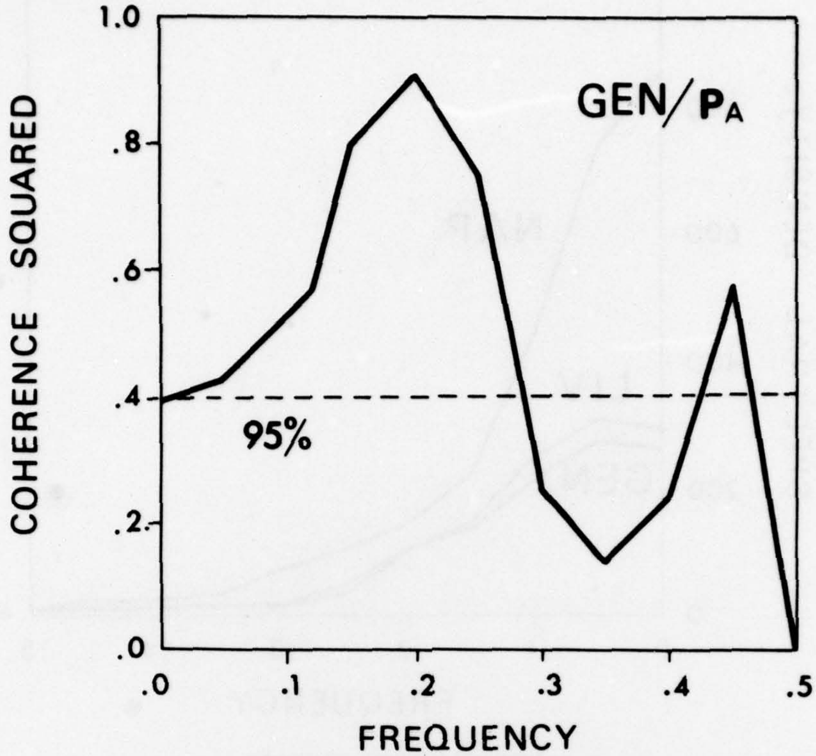


FIG. 6 COHERENCE BETWEEN NON-ADJUSTED GENOVA SEA LEVEL AND ATMOSPHERIC PRESSURE.

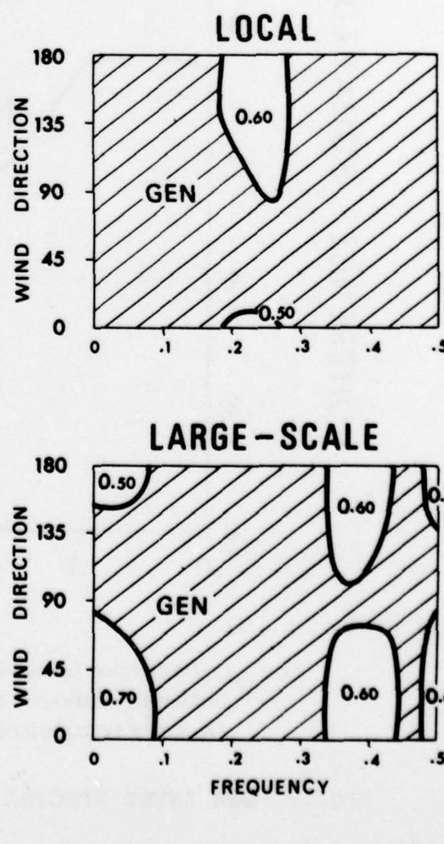


FIG. 7
COHERENCE, AS A FUNCTION OF WIND DIRECTION, BETWEEN ADJUSTED GENOVA SEA LEVEL AND LOCAL AND LARGE-SCALE WIND STRESSES. The shaded area is below the 95% significance level, peak values are shown. (A direction of 0° represents a wind blowing towards the east, 90° a wind towards the north.)

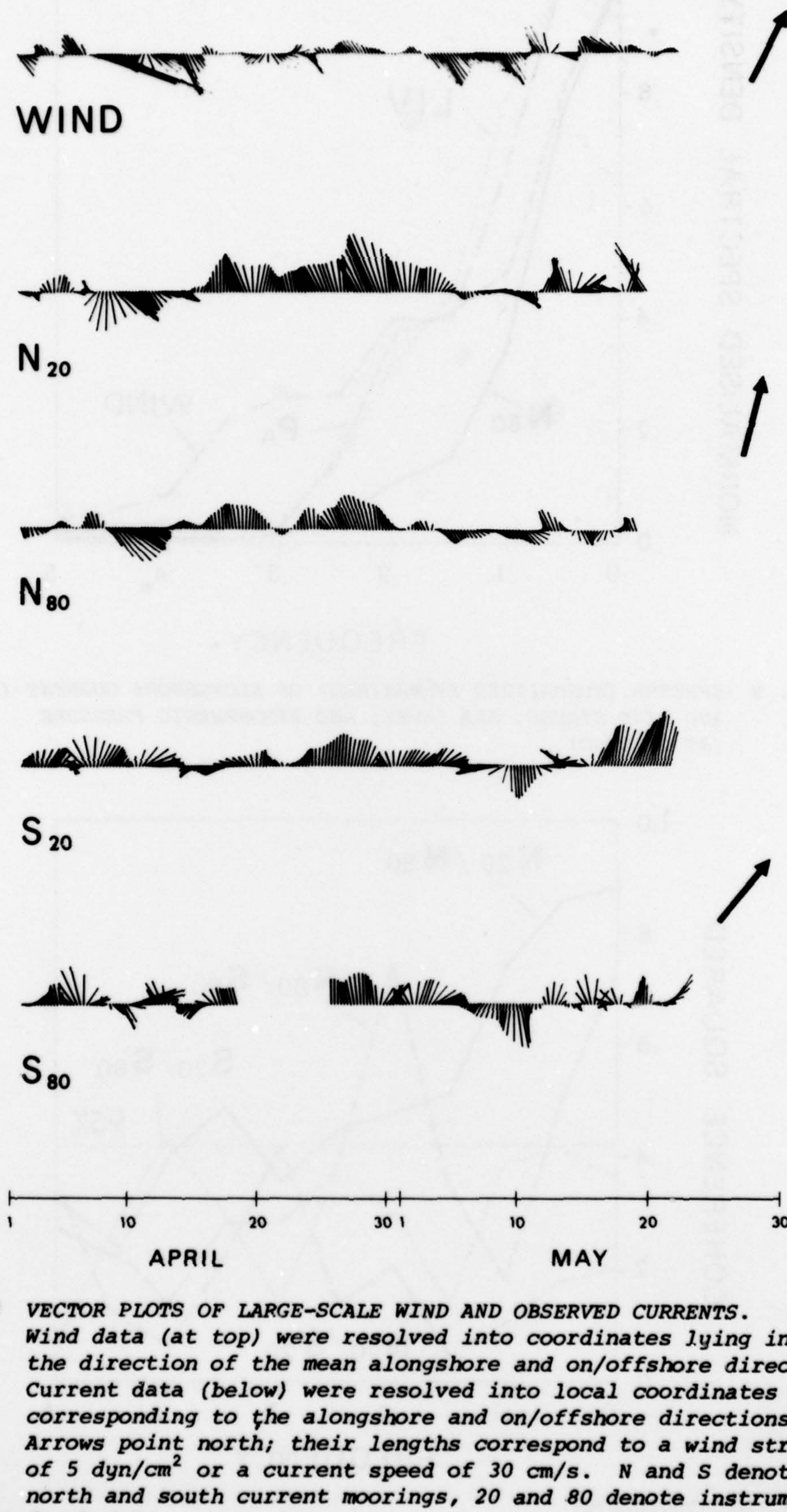


FIG. 8 VECTOR PLOTS OF LARGE-SCALE WIND AND OBSERVED CURRENTS. Wind data (at top) were resolved into coordinates lying in the direction of the mean alongshore and on/offshore directions. Current data (below) were resolved into local coordinates corresponding to the alongshore and on/offshore directions. Arrows point north; their lengths correspond to a wind stress of 5 dyn/cm^2 or a current speed of 30 cm/s. N and S denote north and south current moorings, 20 and 80 denote instrument depth (m).

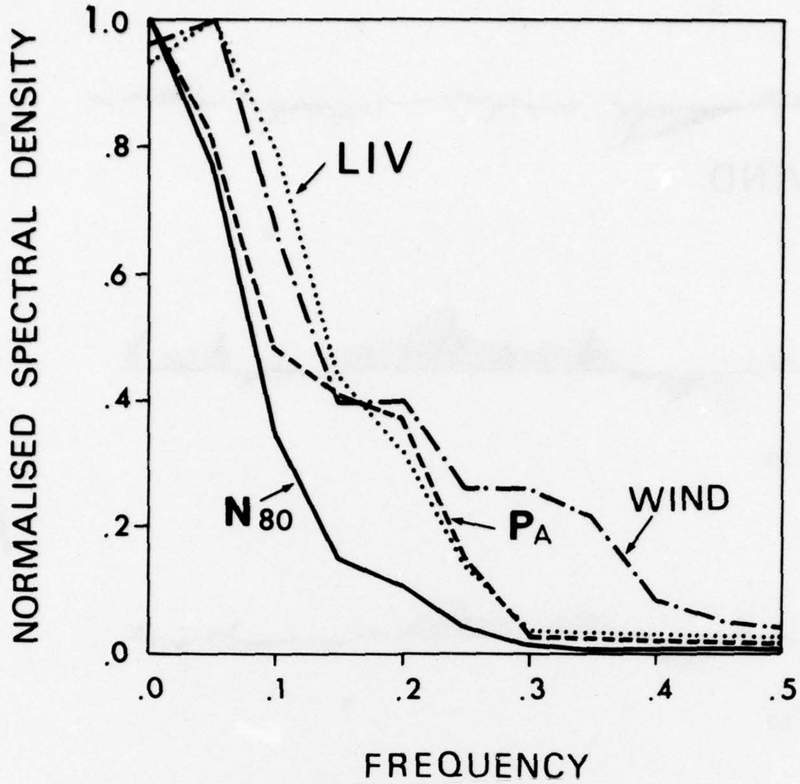


FIG. 9 SPECTRA (NORMALIZED BY MAXIMUM) OF ALONGSHORE CURRENT (N_{80}) AND WIND STRESS, SEA LEVEL, AND ATMOSPHERIC PRESSURE (AT LIVORNO)

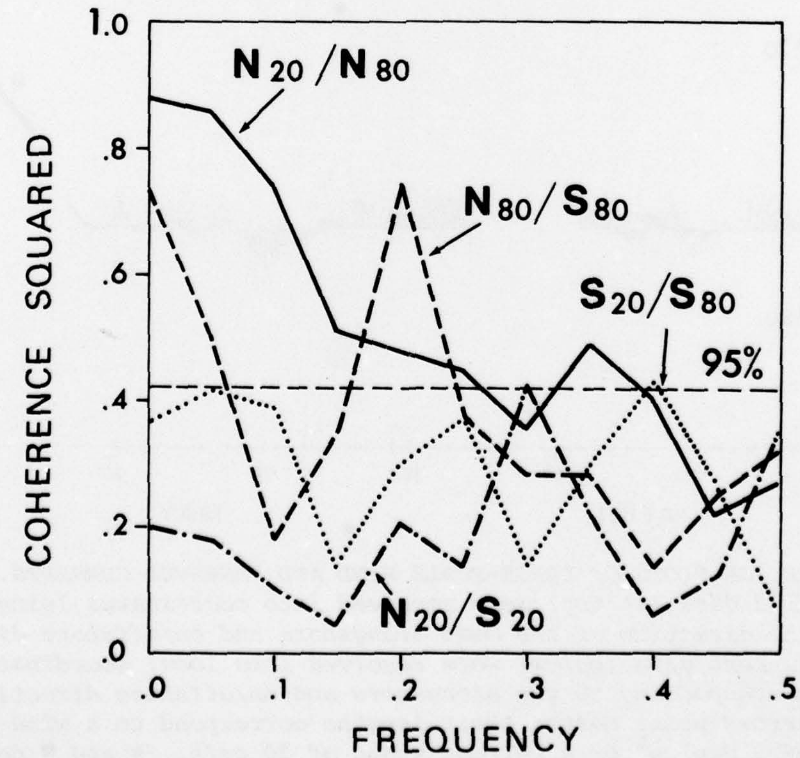


FIG. 10 COHERENCES

a. Between selected pairs of alongshore current records.

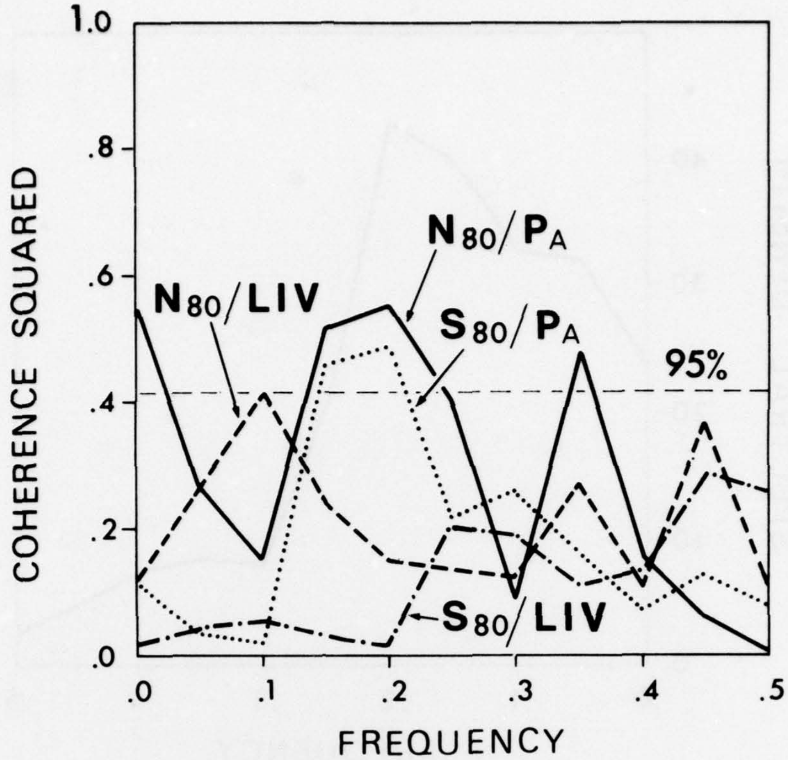


FIG. 10 COHERENCES
b. Between the currents and sea level and atmospheric pressure (at Livorno)

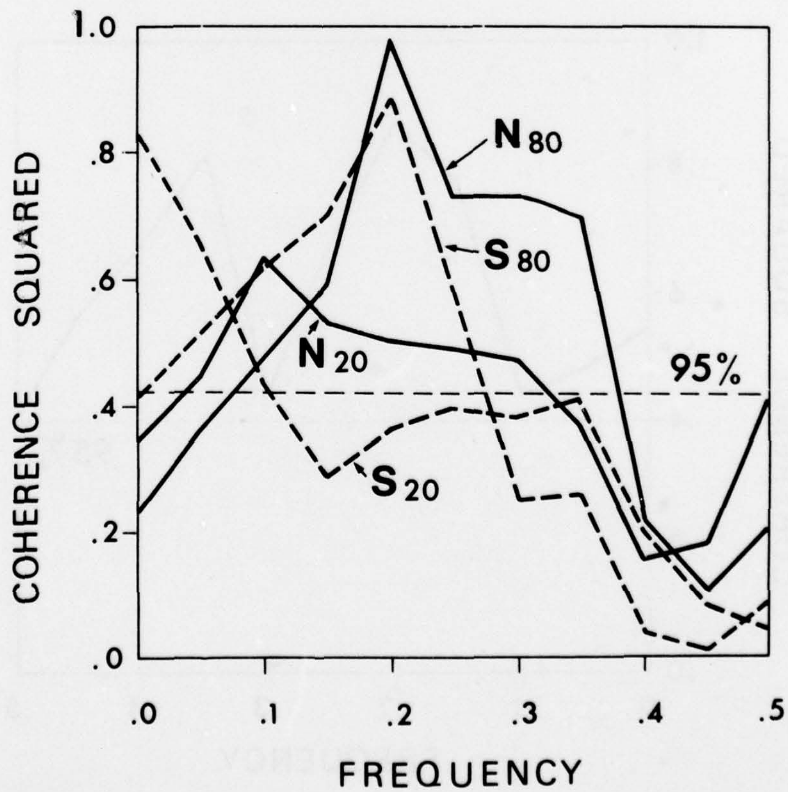


FIG. 10 COHERENCES
c. Between the currents and the alongshore wind stress.

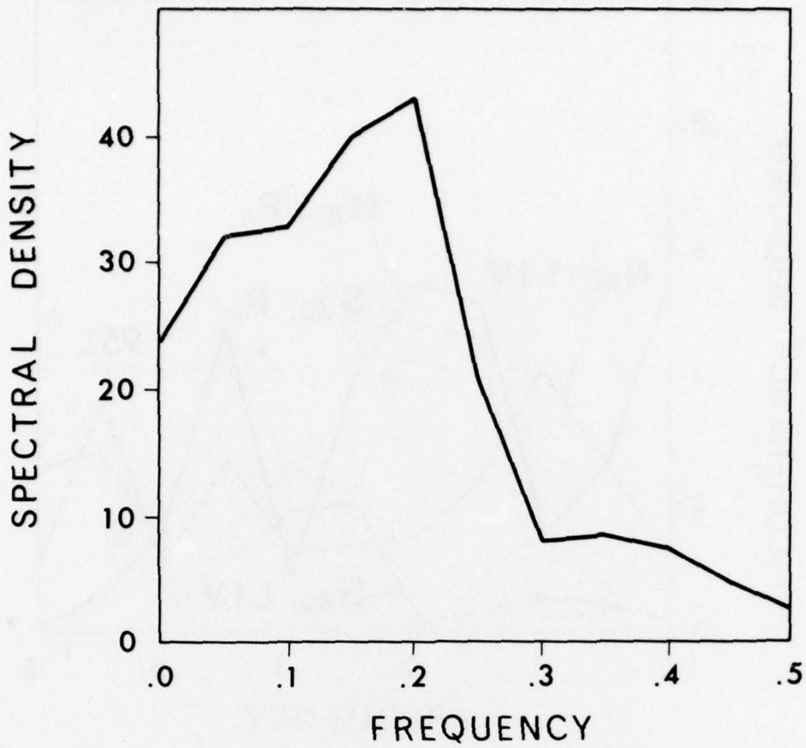


FIG. 11 CURL OF THE WIND STRESS.
a. Spectrum.

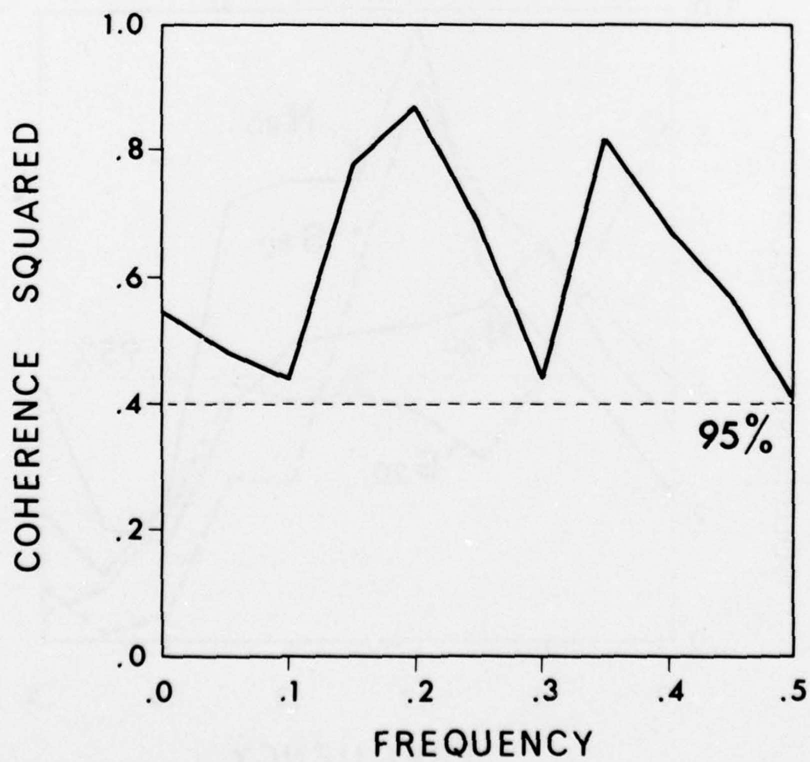


FIG. 11 CURL OF THE WIND STRESS.
b. Coherence between wind-stress curl and atmospheric pressure

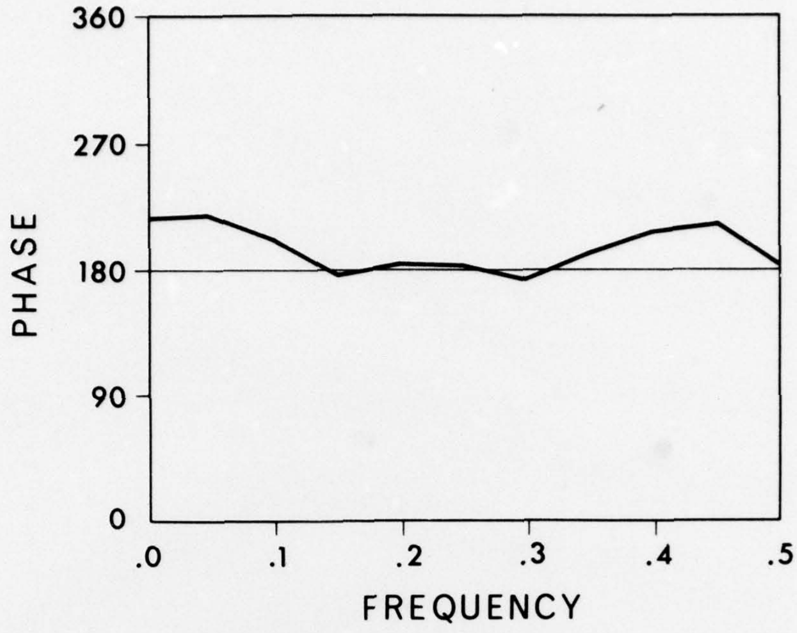


FIG. 11 CURL OF THE WIND STRESS.
c. Phase difference between wind-stress curl and atmospheric pressure

INITIAL DISTRIBUTION

MINISTRIES OF DEFENCE

	Copies
MOD Belgium	2
DND Canada	10
CHOD Denmark	8
MOD France	8
MOD Germany	15
MOD Greece	11
MOD Italy	10
MOD Netherlands	12
CHOD Norway	10
MOD Portugal	5
MOD Turkey	5
MOD U.K.	16
SECDEF U.S.	61

NATO AUTHORITIES

Defence Planning Committee	3
NAMILCOM	2
SACLANT	10
SACLANTREPEUR	1
CINCWESTLANT/COMOCEANLANT	1
COMIBERLANT	1
CINCEASTLANT	1
COMSUBACLANT	1
COMMAIREASTLANT	1
SACEUR	2
CINCNORTH	1
CINCSOUTH	1
COMNAVSOUTH	1
COMSTRIKFORSOUTH	1
COMEDCENT	1
COMMARAIRMED	1
CINCHAN	1

SCNR FOR SACLANTCEN

	Copies
SCNR Belgium	1
SCNR Canada	1
SCNR Denmark	1
SCNR Germany	1
SCNR Greece	1
SCNR Italy	1
SCNR Netherlands	1
SCNR Norway	1
SCNR Portugal	1
SCNR Turkey	1
SCNR U.K.	1
SCNR U.S.	2
SECGEN Rep.	1
NAMILCOM Rep.	1

NATIONAL LIAISON OFFICERS

NLO Canada	1
NLO Denmark	1
NLO Germany	1
NLO Italy	1
NLO U.K.	1
NLO U.S.	1

NLR TO SACLANT

NLR Belgium	1
NLR Canada	1
NLR Germany	1
NLR Greece	1
NLR Italy	1
NLR Norway	1
NLR Portugal	1
NLR Turkey	1

Total initial distribution	232
SACLANTCEN STI Library	10
SACLANTCEN STI Stock	38
Total number of copies	280